TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 844

INVESTIGATION OF THE FORCES ACTING ON GLIDERS IN AUTOMOBILE-, PULLEY-, WINCH-, AND AIRPLANE-TOWED FLIGHT

By W. B. Klemperer
Southern California Soaring Association, Inc.

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SUMMARY

The magnitude, the direction, and the fluctuation of towing forces exerted upon gliders by towing them aloft behind an automobile, by means of a winch, and by airplane were measured under a variety of conditions covering a range from gentle to severe types of operation. For these tests the towing forces did not exceed 92 percent of the gross weight of the glider.

The results indicate that in pulley and winch towing the towing forces are of about the same magnitude as in automobile towing. Speed increases in the accelerated phases of the towing jerks encountered in airplane towing can readily become critical as speeds in excess of placard speeds can be attained. Passage through the slipstream of the towing airplane can be equivalent to a severe gust that, at high speed, may impose high wing loads and require large control moments.

INTRODUCTION

A previous investigation into the nature and the magnitude of the towing forces exerted on gliders has been reported in reference 1. That investigation was limited to three utility types of glider and to automobile and airplane towing. The tests indicated that the towing forces depend largely upon the towing technique, that under favorable conditions they are insignificant but that in deliberately rough maneuvers, simulating extremely crude and inexperienced handling, they can exceed one and one-half times the gross weight, and that twice the gross weight probably could be assumed as a reasonable design load limit.

Since the publication of reference 1, the Civil Aeronautics Authority has promulgated regulations (reference 2, pp. 20, 21) from which the following passages referring to towing forces are quoted:

"05.250 General. The following requirements do not apply to the entire glider structure, but have particular reference to the towing and launching, and holding fittings (and/or mechanisms) and the structures to which they are attached. These requirements are somewhat arbitrary in nature and will be suitably revised when satisfactory test results are available. A minimum-limit factor of safety of 1.0 and a minimum ultimate factor of safety of 1.5 shall be used, unless otherwise specified. See also Paragraph 05.27 for multiplying factors of safety required in certain cases.

"05.251 A limit load of 1200 pounds or 3.0 times the gross weight, whichever is greater, shall be assumed to act in the following separate cases:

(a) Forward at the towing and launching fitting (or mechanism), and aft at the rear holding fitting.

(b) At the towing and launching fitting, and directed forward and upward at an angle of 30° with the longitudinal axis.

(c) At the towing and launching fitting, and directed forward and downward at an angle of 75° with the longitudinal axis.

(d) At the towing and launching fitting, and directed forward and sideward at an angle of 30° with the longitudinal axis.

"05.252 Unless the strength of the wing in resisting rearward acting chord loads is equal to or greater than the strength against forward acting chord loads, suitable provision shall be made to provide adequate strength of wing drag trusses to resist chord inertia loads developed in shock chord and winch launches."

In order to extend quantitative experience to cover more broadly commonly used glider and sailplane types and varieties of towing methods and flight conditions, additional tests were organized during 1940 and 1941 under contract for the NACA. These additional tests, described herein, were conducted by the Southern California Soaring Association, Inc., a group affiliated with the Soaring Society of America, Inc., and assisted by some members of the Avions, an organization of air-minded young high-school students sponsored by the National Aeronautical Association.

TEST EQUIPMENT

Gliders

The gliders flown in the tests comprise representative current types. The accompanying photographs (figs. 1 to 4) show the gliders used in the investigation. Table I shows the various dimensions and data that have bearing upon the interpretation of the tow-test results.

The Bowlus Baby Albatross and the Briegleb BG6 gliders (figs. 1 and 3) are intermediate types commercially manufactured and popular for training and soaring contests. The Stick and the Jensen gliders (figs. 2 and 4) are good examples of experienced home building.

Typical of the Bowlus glider is the very small cockpit nacelle and the slender tail boom that eliminates a complete fuselage. In Expedition I the Bowlus glider was equipped with a fixed stabilizer and conventional trailing elevators, whereas in Expedition II the elevator was of the balanced "pendulum" type without any fixed stabilizer, which arrangement is provided as standard equipment of this type of glider. The other types tested had conventional fuselages and empennages.

The Stick glider was home-built by Herman Stiglmeier who used a Grunau II (Baby) wing and combined it with a fuselage design of his own. The Jensen two-seat sailplane, the seats side-by-side, was designed and home-built by Volmer Jensen. It has a highly tapered wing of symmetrical profile; with the NACA 0018 airfoil at 7° incidence at the root tapering to the NACA 0012 airfoil and 3° incidence at the tip, and with pronounced dihedral. The wing is equipped with spoilers and landing flaps, the latter extending over the inner third of the wing span. The empennage and the fuselage are of conventional plywood construction. On flights 30 through 33 the glider was towed up with the flaps approximately 15° down. Each of the gliders was equipped with a single wheel approximately under the center of gravity with a nose-landing skid ahead of it.

Instruments

The following instruments were carried aboard the glider during the tests:

(a) A 1-square-inch hydraulic piston-type tensiometer, made by V. Jensen and H. J. Stiglmeier, transmitting oil pressure through a flexible hose to an oil pressure gage of either 500- or 1000-pound range (fig. 5), was used to measure the towing forces. The tensiometer was repeatedly calibrated. A calibration chart is presented in figure 10.

(b) A motion-picture camera mounted on an outrigger extending forward below one wing (see fig. 1) was used in Expeditions I, II, III, and IV for recording in flight the readings of an improvised external instrument board. In Expeditions V to VII the camera was mounted above and back of the pilot's shoulder to photograph the instrument board in the glider cockpit.

(c) A second motion-picture camera mounted in the nose of the glider was used in the airplane towing flights of Expedition V to photograph the towing ship.

(d) External instrument board (figs. 1, 2, and 6), containing an altimeter, a rate-of-climb meter, an airspeed meter, and (in Expeditions III to VI) a clock having a 1/4-second escapement.

(e) A protractor (fig. 6) mounted at the towing hook for determining the angle between the towline and the fuselage reference line.

TESTS

Towing Technique

The present tests comprise several towing techniques. In Expeditions I, II, and VI the glider was towed aloft behind an automobile. In these tests, which were made on a desert dry lake whose immense perfectly flat, smooth area permits a car to be driven at 50 to 60 miles per hour for several miles in any direction, a long towline was used. The towline consisted of 1200 feet of number 12 galvanized fence wire in Expedition II and a 50-foot length of 3/8-inch Manila rope snubber line at each end of the 1200 feet of steel wire in Expedition I; in Expedition VI the towing wire was 1800 feet long, 14 gage, with 25 feet of snubber rope inserted at the upper end only and with a 3-foot parachute snapped to the junction. The snubber ropes broke in flight 2 (at lower end) and flight 3 (at upper end) soon after the start when an inexperienced tow-car driver shifted jerkily into high gear. In flight 5 the towing wire broke at a kink, at low altitude. In all other flights the towline was released deliberately by the pilot under moderate load. In the other flights the tow car accelerated steadily and cruised at speeds between 40 and 55 miles per hour. In the dry-lake operation the glider could hang on for several minutes and execute turns while still in tow. The towing cars were a 1939 Lincoln-Zephyr sedan in Expedition I, a 1936 Ford convertible in Expedition II, and a 1938 De Soto sedan in Expedition VI.

Expedition IV was devoted to the so-called pulley method in which the rope is slung over a pulley fastened to the rear bumper of the towing car (fig. 7) and the end of the rope is anchored on a "dead-man" or stake driven into the ground. This method is resorted to where the runway for the car is extremely short or so rough as to limit the car speed. The initial towing speed is twice the car speed. In the steeper phases the pulley method is comparable to the winch inasmuch as its free line gets shorter and shorter. The towline was a 1/2-inch Manila rope. The pulley had a 3-inch sheave diameter. A 1927 Chevrolet coupé served as towing car and was driven at 17 to 20 miles per hour. The towing cars were driven by drivers having experience in glider towing except in the two instances previously mentioned.

In Expedition III the glider was launched by means of a power winch. This winch had been built by Jay Buxton in 1936 and had been used in over 1500 launchings including three regional soaring contests. The winch is shown in figure 8. It serves to wind the towing rope on a drum, the diameter of which grows from 10 inches at the beginning to 18 inches when full of rope. The rope is led over an overhead guide pulley and is evenly distributed over the 20 inches of drum width by a spooling device manually controlled by the winch operator. The drum is directly driven by the drive shaft of a 6-cylinder, 1928 model Studebaker automobile engine. The clutch, the gear, the gas pedal, and the shaft brake were arranged to be operated from a seat facing the glider. All of the present winch launchings were made in second gear without shifting. The towline consisted of 7/16-inch Manila rope, over 2400 feet of which was payed out from the winch to the glider to be launched. About 1500 feet of this rope was hauled in by the winch, which was smoothly accelerated to full speed and finally slowed down to signal the pilot that he should release. The winch was operated by an experienced operator, himself a glider pilot.

In Expeditions V and VII the glider was towed behind an airplane. The towing plane was a Spartan open cockpit two-seat biplane NC 856M powered by a 175-horsepower J-6-5 Wright engine. The line, the spliced-in end ring of which was attached to a quick-release hook improvisedly mounted on the tail-wheel fork of the towing airplane (fig. 9), had a length of approximately 450 feet. It consisted of 450 feet of 5/16-inch Manila rope in flights 24, 25, and 26. After it had eventually broken in flight at a worn splice knot, a length of approximately 350 feet of number 11 steel wire to which was spliced 100 feet of 5/16-inch Manila rope at the rear end was substituted in flights 27 and 28. In flights 34 and 35 a Manila rope of 7/16-inch minimum diameter was used. This rope broke in a violent maneuver in flight 34, whereupon the ends were knotted together for the last short flight.

In these airplane towing flights the "locomotive" airplane climbed steadily to about 2000 feet, flying either straight or making gentle turns until the glider pilot released at his end, whereupon the towing airplane would return to the airport to drop the line and land. The towing pilot reported that the drag of the glider decreased the climb rate of the airplane from about 900 feet per minute to about 500 or 600 feet per minute and decreased the speed at full power by about 10 to 15 miles per hour.

Towing turns were executed at about a 10° bank. The pitching and the yawing movements applied by the towline to the tail when the glider failed to track were easily corrected by elevator and rudder maneuvers, and the deceleration due to tow-pull peaks was usually small because such peaks were of short duration. The maximum momentary speed drop observed was reported as between 12 and 15 miles per hour and was accompanied by a drop of 70 rpm. The airplane towing pilot tried to hold 60 to 65 miles per hour by his airspeed meter. These flights were made from a level airport in the lowlands.

Maneuvers

The gliders were flown by experienced pilots in all of the experiments. In some of the tests the pilots attempted to fly according to approved conventional towing technique of moderate and steady climbing at moderate speed without excessive or severe maneuvering. In some of the other flights spontaneous porpoising (reference 1) was observed in a mild degree and in many instances the same typical porpoising oscillations were deliberately fanned by the pilot instead of damped, in an effort to simulate typical inexperienced students' mistakes and to create unusually severe two-force peaks. Steep climbs were made deliberately in a few of the flights.

Only casual attention was paid to the lateral and the directional stability. Large rolling amplitudes were repeatedly allowed to build up in several flights. The maintenance of course in tracking was very good in all flights except one when deliberate yawing was practiced.

In the aircraft towing flights the glider was taken off the ground as soon as it attained flying speed and then was flown low to give the locomotive a chance to take off. Normally the glider pilot attempted to track behind the towing airplane and to fly a few feet higher. Repeatedly, however, he would deliberately fly higher, lower, off to one side, or through the propeller slipstream, or he would allow the towline to slacken and then to jerk taut. During part of one flight the glider pilot deliberately made repeated violent veering maneuvers, first allowing the rope to slacken, then turning 15° to 30° away from the path of the towing airplane until the rope snapped taut and jerked the plane, thus imparting a violent yawing moment and a high forward acceleration to it. In the last maneuver, which was particularly vicious, the towline actually broke when the glider veered away to the right while the towing airplane made a left turn. These violent maneuvers were executed to simulate bad pilots' errors. They appeared extreme in severity, rougher than any reasonably trained pilot should inadvertently encounter. The airspeed peaks actually exceeded the placard speed and reached 85 miles per hour, although the towing airplane kept a relatively smooth pace at 60 to 65 miles per hour indicated speed. The jerks did not appreciably affect the towing plane, although its pilot could feel them at the elevator and rudder controls.

Topography of Sites

Wind velocity, gradient, and gustiness are recognized to have a marked influence upon the severity of the towing operation. The topography of the site also influences this severity, inasmuch as it affects the wind structure and the motion of the towing vehicle. The sites at which the present tests were conducted are typical of California glider-activity places.

Rosamond Dry Lake is a perfectly flat dry lake bed covering about 25 square miles, situated in a vast semidesert valley ringed by desert mountain ranges 15 to 25 miles away. It is a favorite and typical Western site for glider-student training. The altitude is approximately 2200 feet. Occasionally good soaring thermals are found there.

Dominguez Field is a typical flat and level lowland type of glider field, about $1\frac{1}{2}$ miles by $\frac{1}{2}$ mile extending in the prevailing wind direction. The elevation is 40 feet. The Dominguez oil-field hills adjoin it to the north. The nearest seashores are 8 miles west and south, but ocean winds are intercepted by the Palos Verdes and by the Torrance oil-field hills.

Gardena Field is an airport used for student training. It has a smooth turf surface and is 6 miles from the coast in flat surroundings. The elevation is 50 feet.

The site at Torrey Pines is a small plateau on a rugged cliff jutting several hundred feet above the ocean and offering an uninterrupted though jagged barrier, which deflects the sea breeze and extends for several miles along the coast north of La Jolla.

Weather

The following is a summary of the meteorological conditions prevailing during the various expeditions at the sites:

Expedition I, October 9, 1940, at noon to Rosamond Dry Lake.- The day was warm, the air temperature was 86°, and the sand temperature was 96°. A high-pressure area was building up over the desert; as a result Los Angeles experienced a heat wave of over 90°. A gusty desert wind of up to 15 miles per hour veering between north and northwest alternated with dead calm.

The small thermal clouds forming and evaporating again at the edge of the dry lake were not reached by the glider. Exploration by airplane revealed strong vertical up- and down-currents over adjoining mountain ranges 20 miles to the south.

Expedition II, October 12, 1940, late afternoon and evening.- The wind died down gradually from 8 miles per hour, north, at 3:30 p.m., to a dead calm before sunset with practically no wind activity aloft. The temperature ranged between 75° and 80° F, and the weather was clear.

Expedition III, November 24, 1940, afternoon, to Dominguez Field.- The sky was clear overhead, but a high overcast drifted in westward from the ocean. The wind was westerly and very slight (3 to 6 mph) on the ground, dying down after 4 p.m. Slightly higher winds aloft were indicated by smoke and steam given off by nearby oil refinery plants.

Expedition IV, February 2, 1941, at Torrey Pines.- The sea breeze was unusually weak, in fact was too slack to support soaring at the cliff, and the flying had to be discontinued when fog drifted in from the ocean.

Expedition V, May 11, 1941, at Gardena.- The weather was fine; the wind veered from the east toward the southwest. The wind speed on the ground averaged less than 5 miles per hour but there were occasional sizable gusts and small thermals.

Expedition VI, June 21 and 22, 1941, to Rosamond Dry Lake.- The weather was cloudless and clear, temperature

85° to 90° F, with a strong gusty desert west wind blowing, wind velocity averaging 12 to 18 miles per hour, with gusts up to 24 miles per hour and lulls down to 8 miles per hour measured 5 to 7 feet above ground. In flights 29 and 33 the air was decidedly rough. On the second day, flights 30 to 31 were made in the morning before the wind had attained full force.

Expedition VII, June 28, 1941, at Gardena.- Appreciable thermal activity and a west wind of approximately 12 miles per hour with occasional gusts to 15 miles per hour were followed by lulls to 7 miles per hour recorded 7 feet above the ground. The weather was clear except for the edge of light ocean fog 6 to 7 miles to the west.

RESULTS AND DISCUSSION

The various flight parameters as evaluated from the motion pictures are shown plotted against both frame sequence and time on figures 11 to 17 for several representative flights. Each of the figures from 11 to 14 comprises several graphs. The top portion of the figures shows the history of towing force and altitude above the field. The center plots show airspeed and towing angle (between fuselage reference line and upper end of towline). The lowermost plots show roll and inclination (fuselage to horizon). Figures 15 and 17 present the results of the airplane towing tests of Expeditions V and VII.

A complete set of figures obtained in the investigation are available for reference at the Washington office of the NACA.

Table I presents a synopsis of the gliders flown, the towing methods used, the number of flights made, and table II a chronological log of the individual flights with an abstract of the results.

The following is a brief survey of the interesting features of these results. The maximums observed in each flight are entered in the synopsis table.

The extreme peaks of the towing force, as observed in the present series of tests, in pounds and in terms of gross weight W are given in the following table.

EXTREME PEAKS OF TOWING FORCE

Glider	Type of locomotion	Force measured (lb)	Force measured (percent W)	Towing-force angle (deg)
Bowlus	Automobile	465	90	51
Jonson	----do----	380	[a]50	------
Bowlus	Pulley	340	72	38
Stick	Winch	480	92	45
Briegleb	Airplane	385	86	In yaw

[a]Observed on maximum pointer but not caught on film.

Extreme peaks of the towing force P, measured at the glider, invariably occurred in the pull-up phase of extreme pitch oscillations. They do not, as a rule, coincide with the steepest pull angles α, because the increased pull tends to reduce the sag of the towline.

The greatest towing force components normal to the wing chord, important as flight loads, can be derived as $P \cos (\alpha + i)$, where i denotes the angle of incidence between the chord and the reference line from which the plotted towing angles were measured. The maximum normal components thus encountered were 360 pounds (0.70 W) in the Bowlus flights, and 350 pounds (0.67 W) in the winch-towed Stick flights.

In the Jansen flights the towing-force angle was not measured. Observations from the ground indicate that an estimate of 50° probably is not far from the maximum attained. This would place the normal force attained at about 250 pounds or 0.33 W, but in those flights the inclinations were kept moderate by the pilot (14° for aircraft reference line, 21° for chord at wing root).

The towing-force extremes are exceptional. Peaks exceeding 80 percent of the extremes were very rare, but 75 percent was attained quite a few times. Steady loads in steep climbs are seen frequently to average 150 to 250 pounds in the automobile-towed Bowlus flight, and 250 to 350 pounds in the winch-towed Stick flight.

In the pulley towings, even though steep climbs as fast as 2400 feet per minute were made, the towing force peaks reached 340 pounds once and 310 pounds several times.

In the automobile-towed Jensen flights the maximum pull of 380 pounds was observed on the maximum pointer but was not caught on the film. This value is only about 0.50 W in spite of the very high wind speeds which prevailed during some of the tests. These towing forces may in part be characteristic of the symmetrical wing profile.

To some extent any such comparative statistical data may be systematically influenced by the differences of prevailing conditions relating to wind, towing speed, and climb. The fact that no peaks observed reached quite as high values in terms of gross weight as those reported in reference 1 is interpreted as indicative of the fact that those deliberate rough-weather flights in 1937, made by an acrobatic-trained pilot, comprised unusually severe maneuvers not easily duplicated under normal training or service conditions.

A little more light was shed on the peculiar pitch oscillations sometimes referred to as porpoising and observed in both automobile and winch towing. The oscillation periods were mostly between 1 and 2 seconds, in some instances very regular. In the Bowlus Baby Albatross flights, the type of elevator did not seem to influence the character of the porpoising behavior, but the impression was gathered that the tendency to porpoise was less with the stabilizer-and-flippers type of empennage than with the undamped pendulum type of elevator.

The porpoising motion is to some extent reflected in the form of the inclination oscillations. Not exactly in phase with the towing force, inclination peaks usually precede the pull peaks by a fraction of the period. This can be interpreted to indicate that inertia forces should not be added to but should be subtracted from towing-pull components as far as wing loads in porpoising are concerned.

That the porpoising phenomenon is not merely a fanned phugoid motion is indicated by the fact that the phugoid frequency of the gliders tested is noticeably slower as observed in free flight after release and after deliberately disturbing a steady glide (5 to 8 sec).

Yawing and rolling up to ±9° and at periods varying from 4 to 11 seconds did not tend to enhance the towing forces measurably in automobile and winch towing, but did so in airplane towing.

Otherwise, the pull in airplane towing was normally quite low. It averaged less than 100 pounds at airspeeds limited by the CAA placard. Occasional peaks occur when the glider, after having coasted on a slack line, begins to lag behind and the bight snaps taut. Peaks registered at only 250 pounds were already felt as severe jolts and caused quick acceleration of the glider. When passing through the slipstream, the glider is thrown somewhat out of its track which may accentuate the next towing-force peak considerably.

The deliberate swerving maneuvers executed on flight 34 must be regarded as unusually violent and departing considerably from conventional practices. Even so, the towing-force peaks stayed mostly below 300 pounds, in spite of the fact that excessively high airspeed peaks were attained. How much the towing force might have increased had the line not broken at 385 pounds in flight 34 at 530 seconds is, of course, unknown. However, the jerks felt in these maneuvers and the longitudinal and veering accelerations imparted to the glider by the towing-force peaks were uncomfortably severe. Yet the forces themselves were actually lower than the maximums observed in automobile, pulley, or winch towing. In view of the acute angles of the towing pull against the wing chord in airplane towing, the contribution of the towing forces to the wing-load factor is rather insignificant, but the speed increases in the accelerated phases of the towing jerks are significant. The increases can readily become critical as speeds in excess of placard speeds can inadvertently be attained and passage through the propeller slipstream can be equivalent to a severe gust which, at excessive flight speed, may impose high wing loads and require large control moments.

Arrangements had been made to carry the towing-force measuring instruments, equipped with a maximum pointer, on a ferry trip in which a Cadet glider (the same one, G10235, on which the 1937 NACA towing tests reported in reference 1 had been conducted) was flown in tow by 560 feet of 5/16-inch Manila rope line behind a Waco UPF7 airplane on May 30, 1941, from Bakersfield to Montebello, California, a distance of 115 miles, 40 miles of which was over the semidesert San Joaquin Valley, 50 miles over the rugged Tehachapi range with peaks of 7000 feet and narrow gorges, while the last 25 miles led over part of the Los Angeles metropolitan area. The towed flight took one hour and fifteen minutes and was made at altitudes up to 8100 feet. The towing airplane was powered by a 210-horsepower Continental engine. Unfortunately, due to some minor installation trouble, no quantitative towing-force measurements were collected from this flight. However, the pilot reported that most of the flight was remarkably smooth and but few jerks were felt, even though airspeeds in excess of 90 miles per hour were occasionally reached and in some places the towing plane flew through fringes of clouds hanging low over the mountains, temporarily blotting out the vision between the two craft. The greater part of the second half of the flight was made above broken clouds where the air was stable. The roughest part of the flight was the part immediately following the take-off when, at high speed and low altitude, thermal currents apparently rising from oil-storage tanks were encountered. The temperature was near 90° F and the weather there was dry and clear. Although about three sizable jolts were felt by the pilot during the climb over the broad valley, they were inconsequential. Most of the time the towline was fairly taut because of the high towing speed which averaged 78 miles per hour. During most of the flight the glider pilot did not feel it necessary to move the control stick more than a fraction of an inch to parry gusts. He flew above the slipstream most of the time. At one instance, however, just before hitting a cloud over the end of Antelope Valley a sharp roll required full opposite control.

CONCLUSIONS

1. The present tests indicate that in normal winch and pulley towing the towing forces are of about the same magnitude as in automobile towing and stay below the weight of the aircraft.

2. In airplane towing the forces are normally low, much less than in automobile or winch launching, and in a less critical direction.

3. Speed increases in the accelerated phases of the towing jerks encountered in airplane towing can readily become critical as speeds in excess of placard speeds can

be attained and passage through the propeller slipstream can be equivalent to a severe gust which, at excessive flight speed, may impose high wing loads and require large control moments.

4. In airplane towing the insertion of a weak link at the rear end of the towline would seem to offer the advantage that it would limit the jerk and in case of line severance, save the glider pilot from the necessity of dropping his end of the line before landing.

5. Although the present tests included several instances of high wind, they afforded no opportunity to learn the effects of bad weather.

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REFERENCES

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2. Anon: Civil Air Regulations. Proposed Part 05 - Glider Airworthiness. C.A.A., June 1940.

TABLE I.- GLIDER CHARACTERISTICS AND LAUNCHING METHOD

Expedition	Glider make and model	Wing area (sq ft)	Span (ft)	Aspect ratio	Weight empty (lb)	Crew weight (lb)	Equipment weight (lb)	Gross weight (lb)	Launching method	Type elevator	Design tow speed (mph)	Identification number
I, II	Bowlus Baby Albatross	156	44' 6"	12.7	300	200	15	515	Automobile tow	I Conventional II Pendulum	55	NX21734
IV	Bowlus Baby Albatross	156	44' 6"	12.7	300	150	20	470	Automobile and pulley	Pendulum	55	N-21742
III	Stiglmeier Stick	160	46' $2\frac{1}{2}$"	13.4	345	160	15	520	Power winch	Conventional	55	N-15539
V, VII	Briegleb BG6	117	32' 3"	8.9	235	180 with chute	35	450	Airplane tow	Conventional	55 (80 airplane tow)	NC28373
VI	Jonson two-seater	180	55' 0"	16.8	430	335	15	780	Automobile tow	Conventional and flaps deflected 15°	75	N-28375

TABLE II.- CHRONOLOGICAL LOG OF FLIGHTS

Expedition number	Flight number	Tow speed **) (mph)	Wind (mph)	Maneuver performed	Number of camera frames	Maximum air speed (mph)	Maximum altitude (ft)	Maximum climb (ft/min)	Maximum tow force P (lb)	Maximum tow angle α (deg)	Maximum inclination (deg)	Maximum roll (deg)
I	1	50	5	Normal climb	661	50	450	900	275	70	23	±7
	2	45	8	Start *)	69	45	—	—	215	(42x)		
	3	45	0-10	Steep take-off *)	97	43	180	750	285	35	24	
II.	4		8	Steep climb and porpoising	173	53	460	1300	465	59	18	±6
	5		2	Take-off *)	100	40	50	—	160	15	13	
	6	53	2	Steep steady climb	353	56	370	900	265	42	16	+4-5
	7	51	1	Moderate porpoising	223	57	400	1200	350	45	14	+4-5
	8		1-2	Steady climb	480	57	500	1000	310	51	14	+2-5
	9		1-2	Porpoising	632	58	560	1000	360	60	16	±9
	10		0	Steady climb	450	55	420	1150	420	57	15	±5
	11	50	0	Steep climb and porpoising	390	51	410	1000	295	49	17	+9-3
III	12		3	Steep climb	395	40	450	1200	390	50(76x)	32	±3
	13		3	Steep steady climb	464	43	590	1150	395	54(89x)	23	+3-2
	14		5	Deliberate porpoising	376	49	570	1200	395	52	24	+3-5
	15		6	Mild porpoising	352	47	630	1300	410	57	26	±3
	16		5	Sharper porpoising	385	45	600	1075	440	55	24	±2½
	17		3	Deliberate violent porpoising	418	45	520	1100	460	55	26	±2
	18		1	Smooth steep climb	377	49	600	1150	440	60	26	+2-1
	19		0	Steep deliberate porpoising	406	44	560	1080	475	55	27	+3-2
	20		0	Deliberate wild yawing	392	45	540	1090	370	52(66x)	25	+3-4½
IV	21	2x17	11	Steep climb	390	39	200	1300	310	52(60x)	23	
	22	2x20	2	--- do ----------	290	47	265	1600 (2400)	340	57	24	
	23	2x20	1	--- do ----------	280	42	215	1400	310	42	30	
V	24	60-65	2	Normal climb	(500+ (+694	64½	1320		140			
	25	60-65	3	--- do ----------	(1345 (+906	68	1400	450	200			
	26	60-65	4	--- do ---- *)	(1400+ (+1092	70	1510	(700)	230			
	27	60-65	4	Test hop	(84 (+825	64	1680	(800)	170			
	28	60-65	4	Flew through slipstream	(3933 (+2090	72	2060	600	185	±7	±7	
VI	29	40	18	Slow climb	734	57	495 (800)	400 (900)	320 (385)		14	
	30	40	12	Moderate climb	661	51	600	900	300		14	
	31	40	12	Steady climb	644	52	970	700	345		14	
	32	40	15	Moderate climb	792	56	780	1000	300		13½	
	33	40	18	Slow climb	470	57	985	400	335		10	
VII	34	65	12	Violent yaw jerks *)	3725	85	2370	500	385			
	35	62	10	Cut turns	182	61	900+		210			

**) As reported by the towing personnel
*) Line broke
x) At low load only
(For short period only
() Observed but not recorded

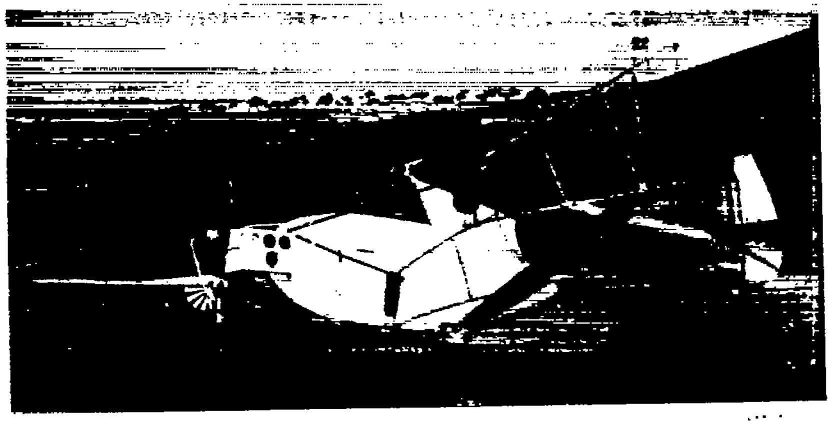

Figure 1.- Bowlus Baby Albatross glider with camera on collapsible outrigger and instruments.

Figure 2.- Stiglmeier "Stick" glider.

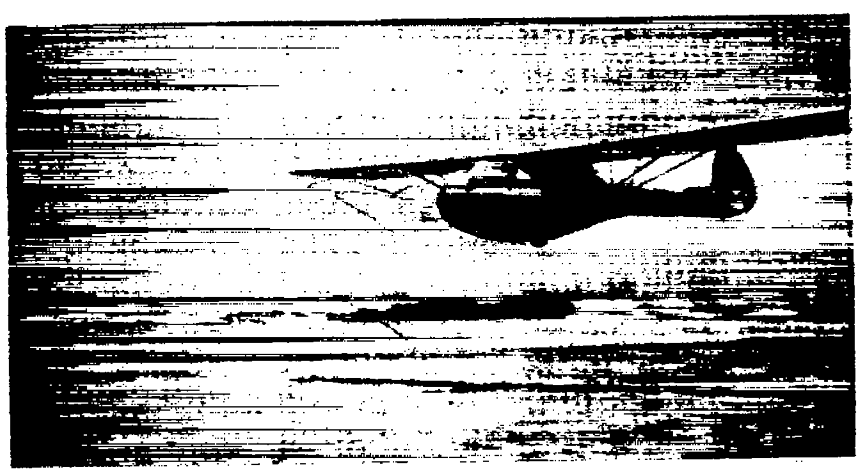

Figure 3.- Briegleb BG 6 glider.

Figure 4a.- Jensen two-seater sailplane.

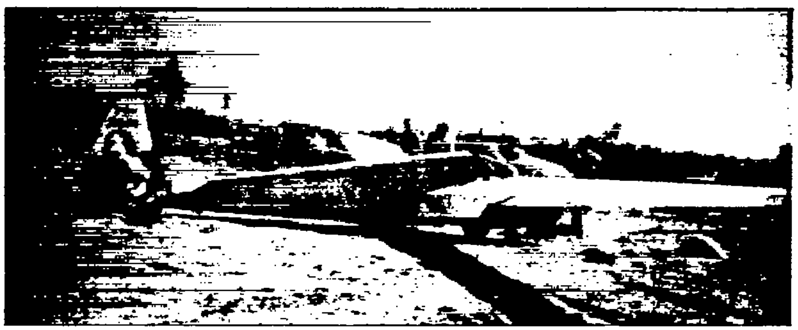

Figure 4b.- Jensen two-seater sailplane.

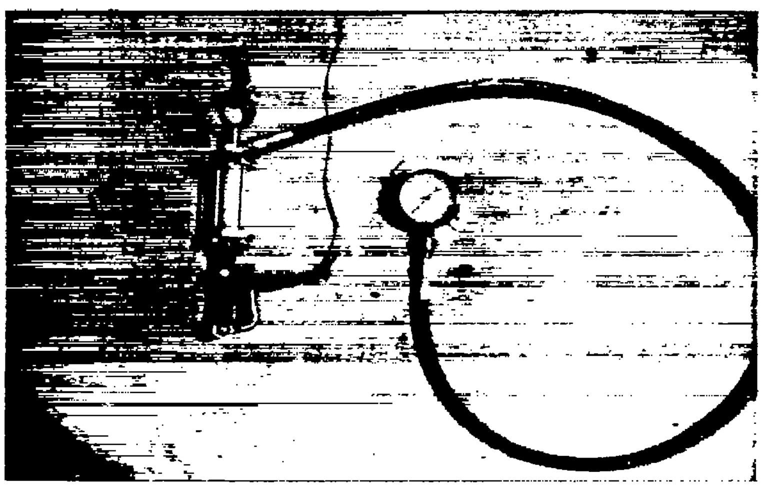

Figure 5.- Hydraulic tensiometer.

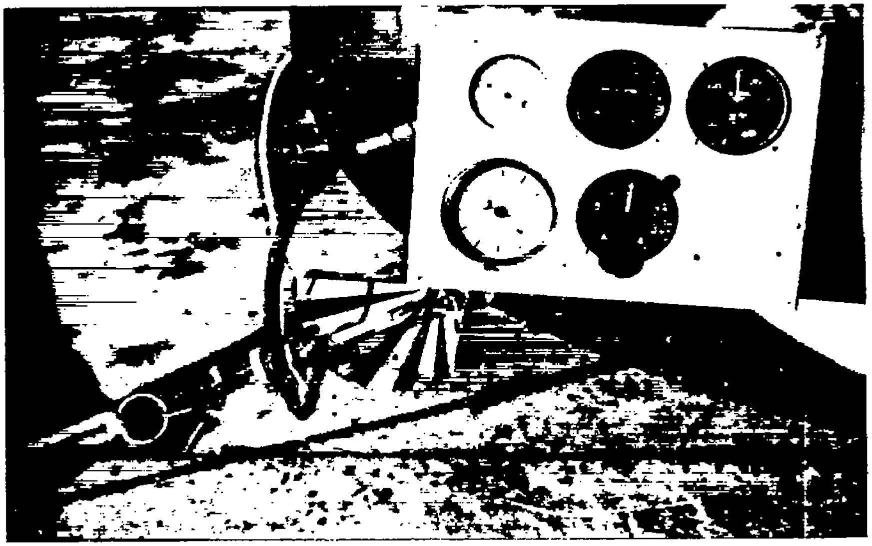

Figure 6.- Tow test equipment on Stiglmeier "Stick".

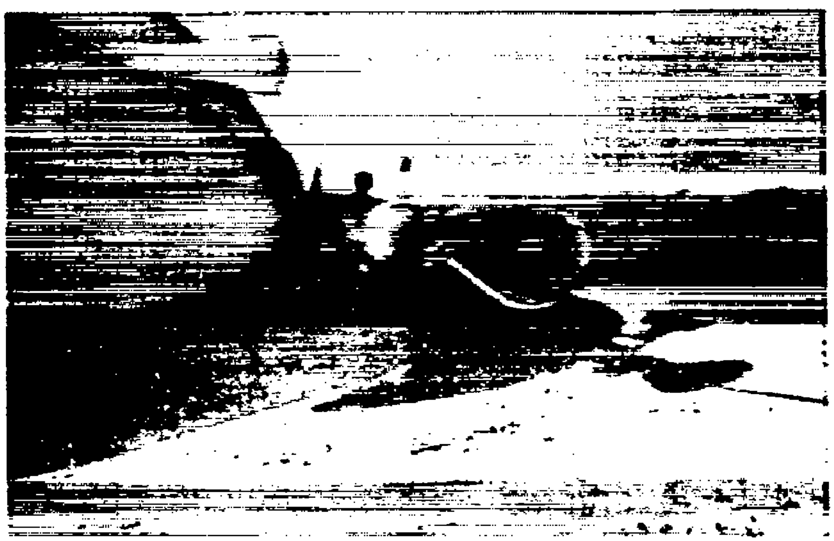

Figure 7.- Car pulley for pulley tow.

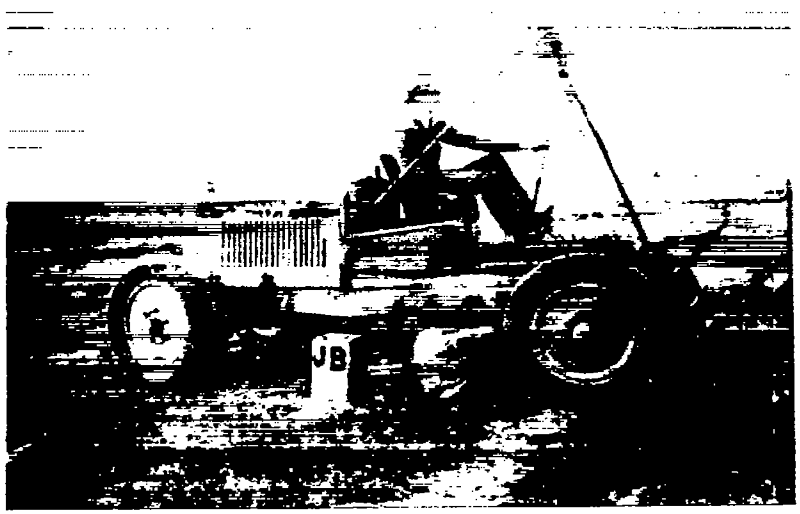

Figure 8.- Buxton winch.

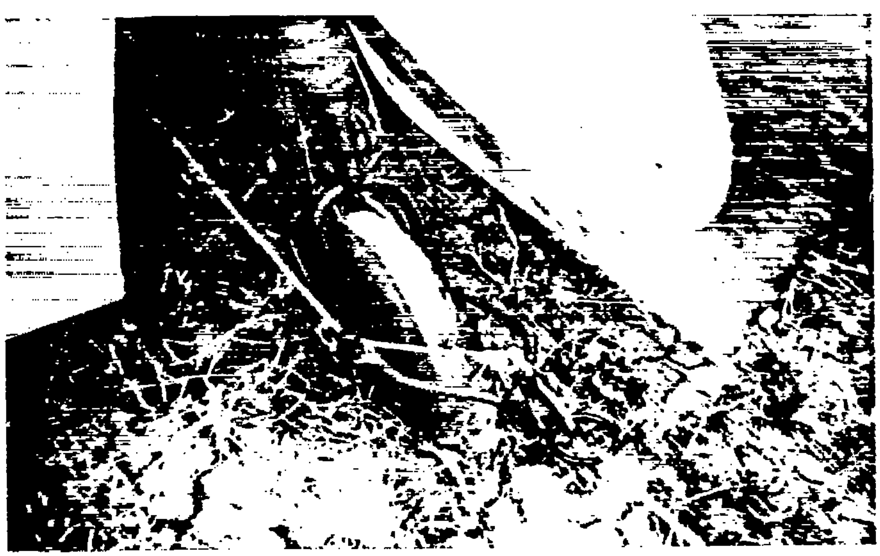

Figure 9.- Release hook on tow plane tailwheel fork.

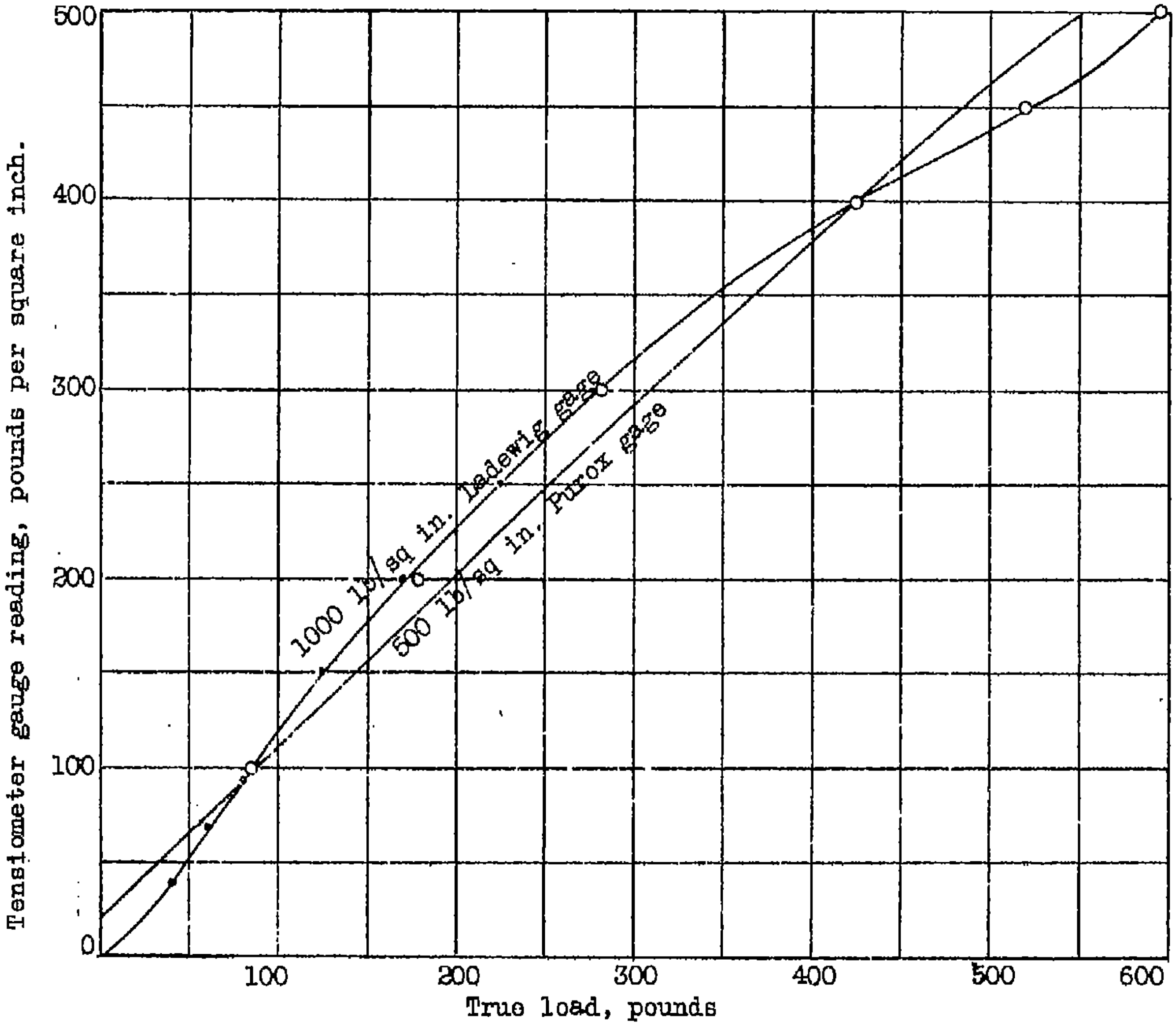

Figure 10.- Calibration of tensiometer.

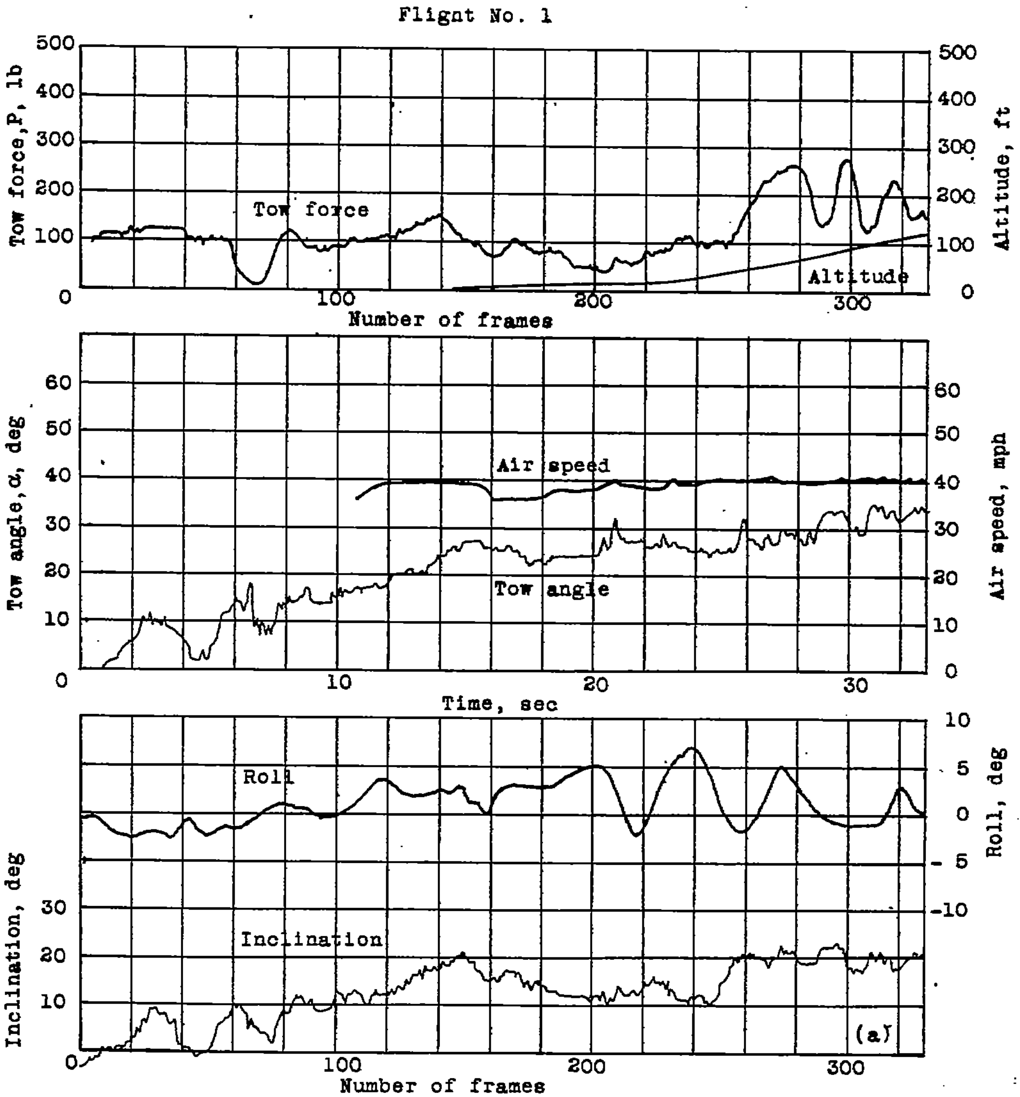

Figure 11(a,b).- Results of flight of Bowlus Baby Albatros glider with conventional elevator in automobile tow.

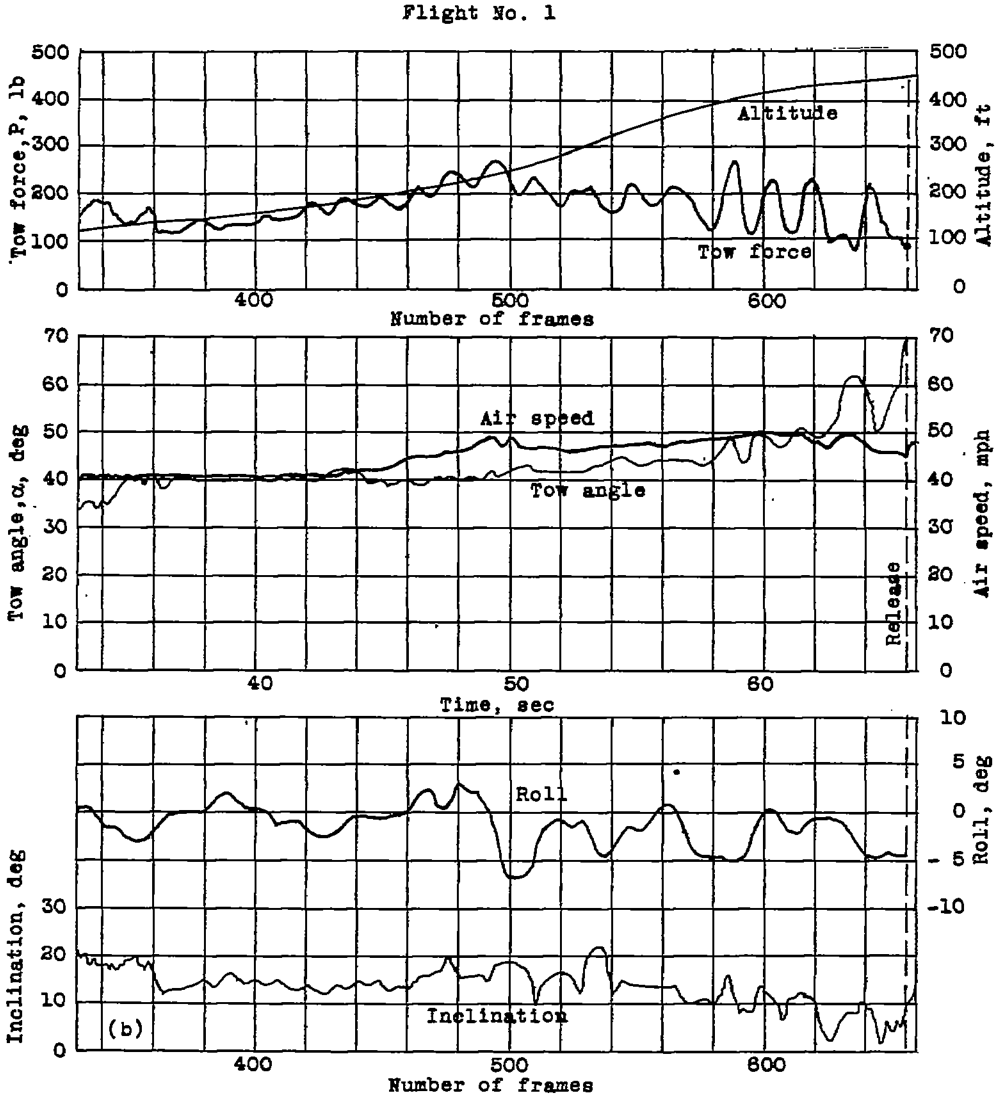

Figure 11.- (Concluded)

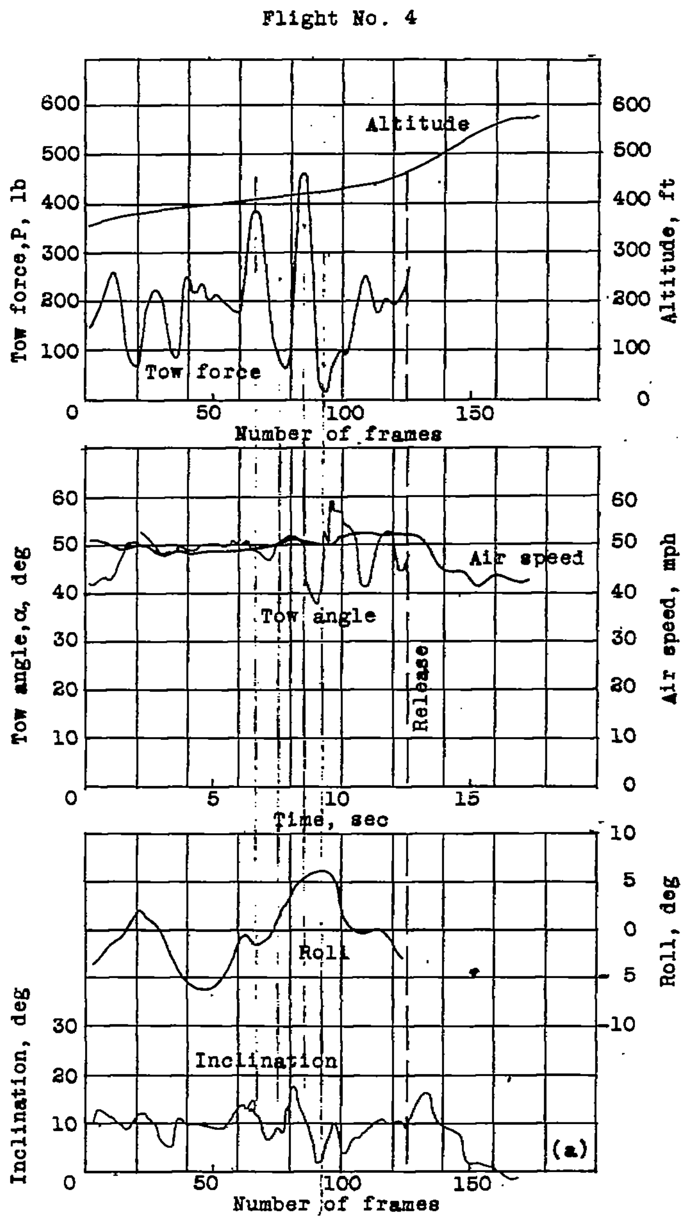

Figure 12(a,b).- Results of flights of Bowlus Baby Albatros glider with pendulum elevator in automobile tow.

Flight No. 6

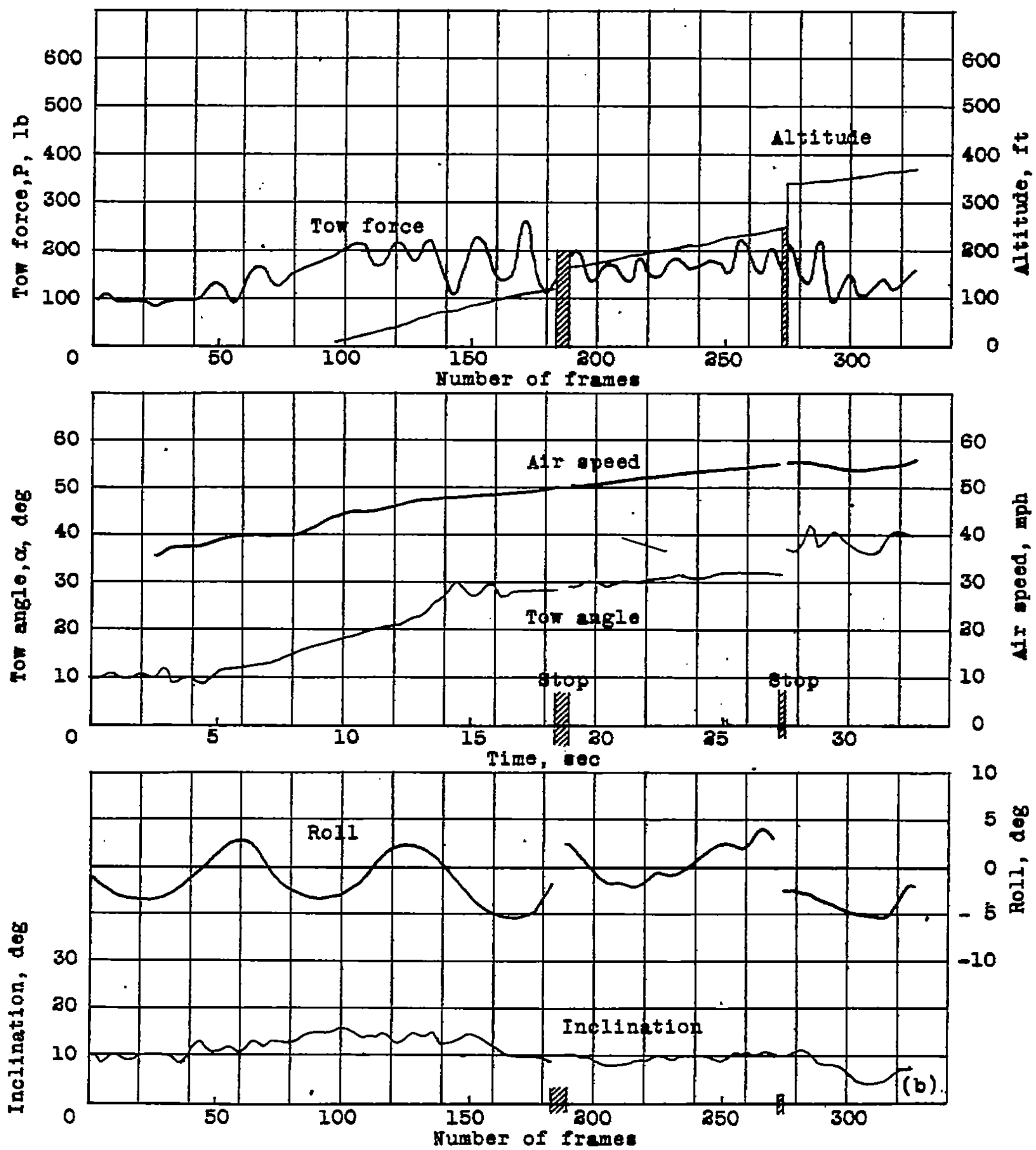

Figure 12.- (Concluded)

Flight No. 18

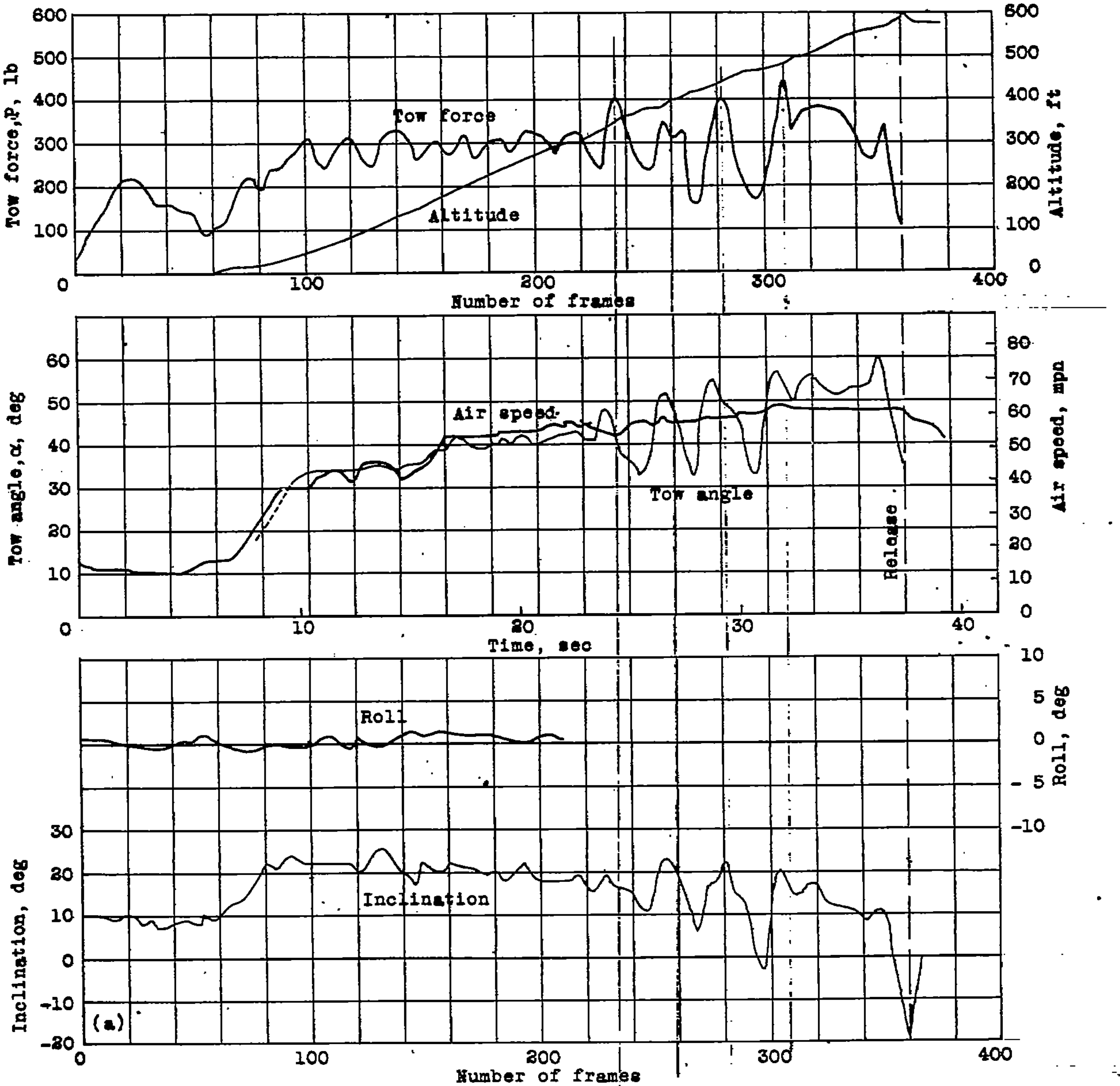

Figure 13(a to c).- Results of flight of Stiglméier "Stick" glider launched by power winch.

Flight No. 19

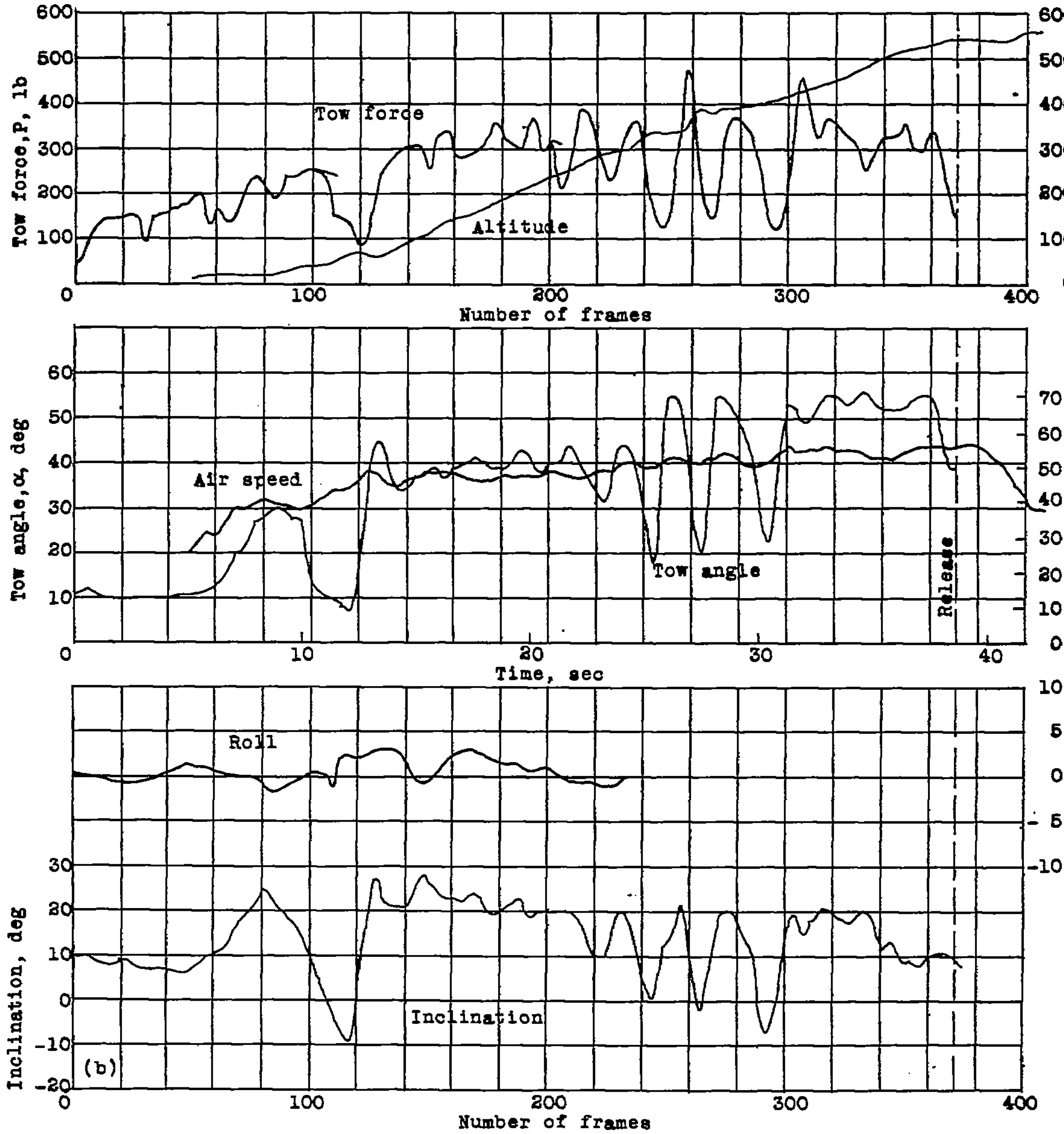

Figure 13.- (Continued)

Flight No. 20

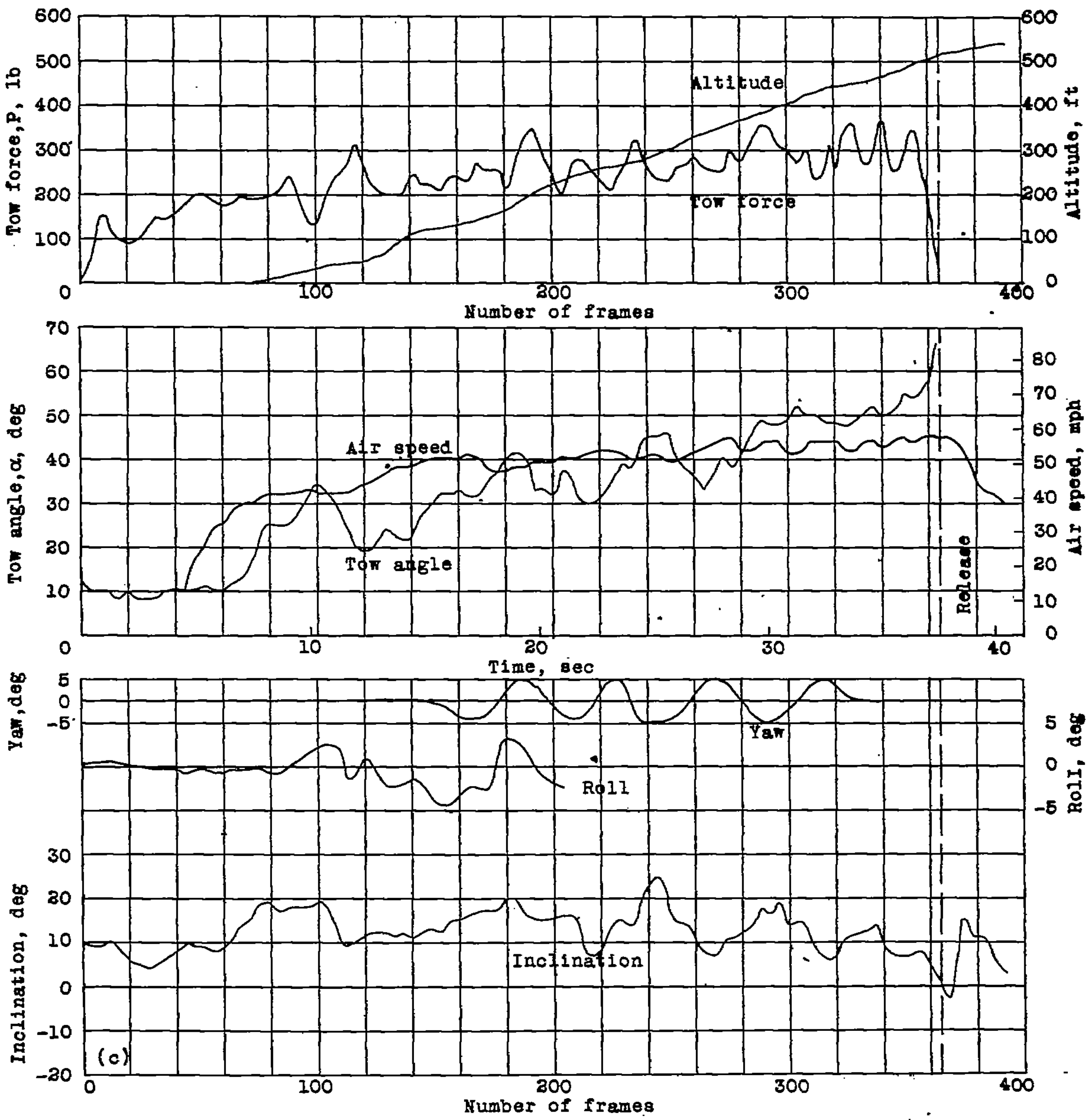

Figure 13.- (Concluded)

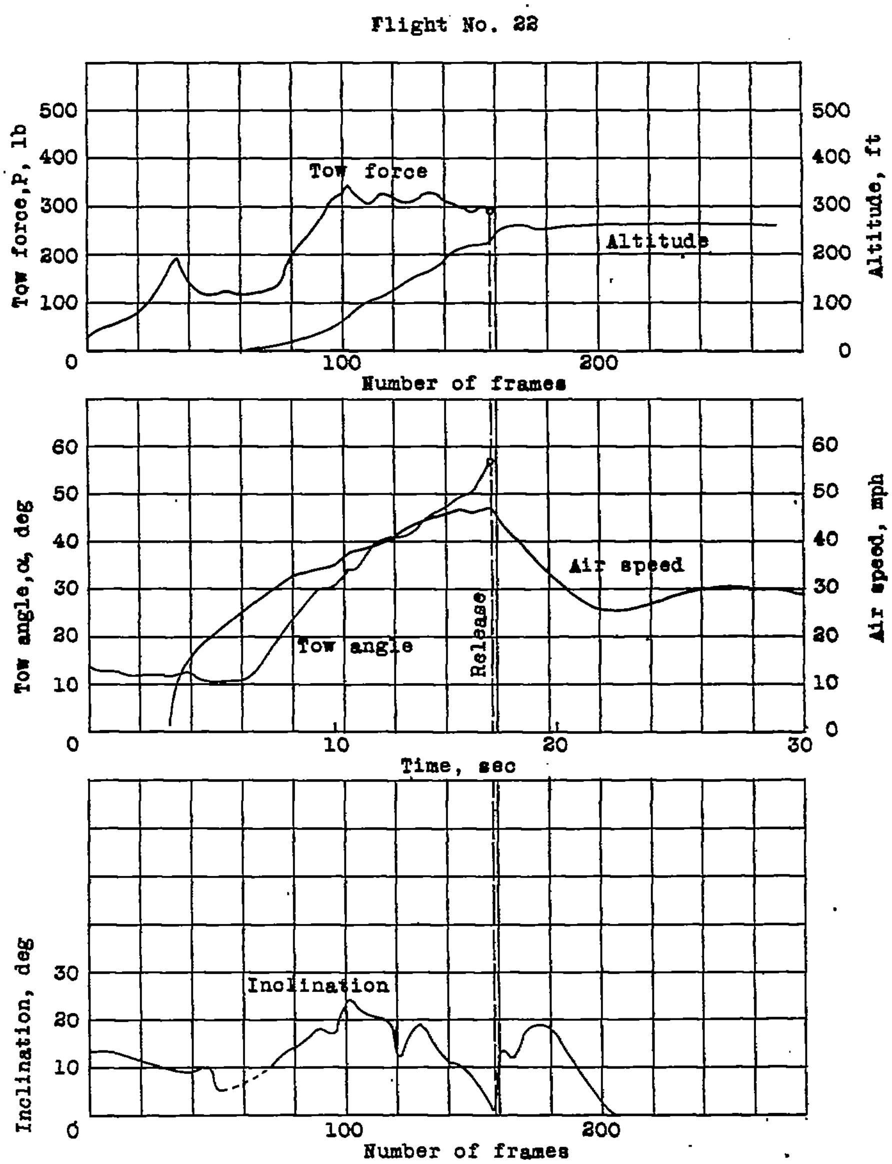

Figure 14.- Results of flight of Bowlus Baby Albatros glider with pendulum elevator launched by the pulley method of automobile tow.

Flight No. 28

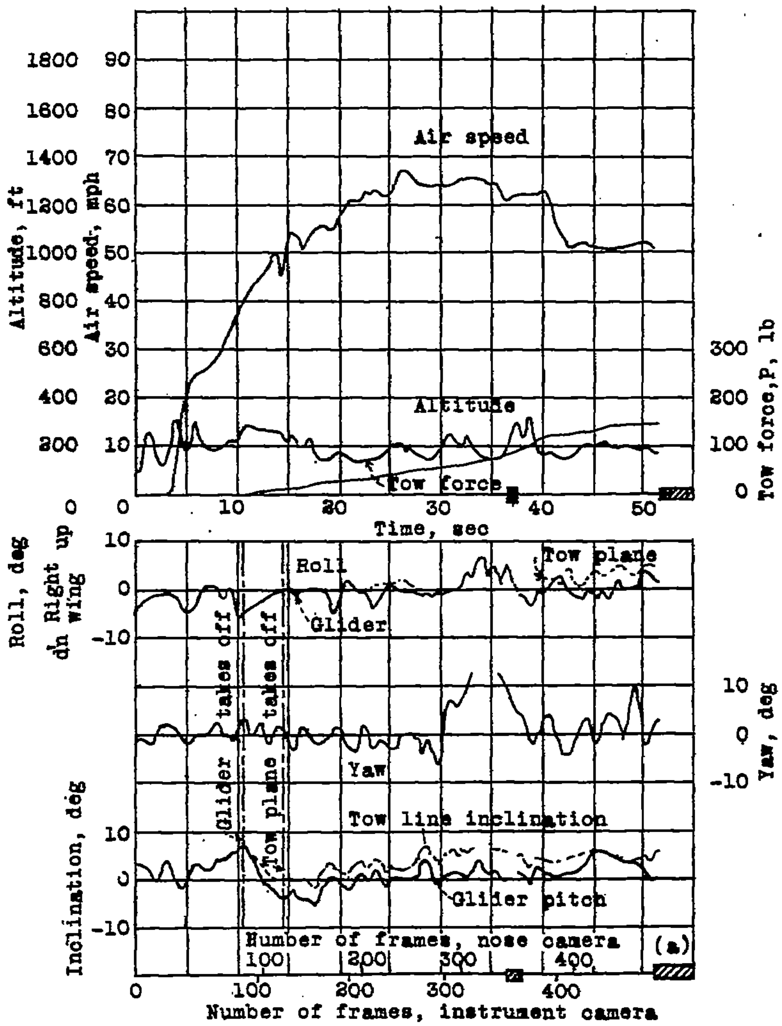

Figure 15(a to d).- Results of flight of the Briegleb BG6 glider in slipstream of tow airplane.

Flight No. 28

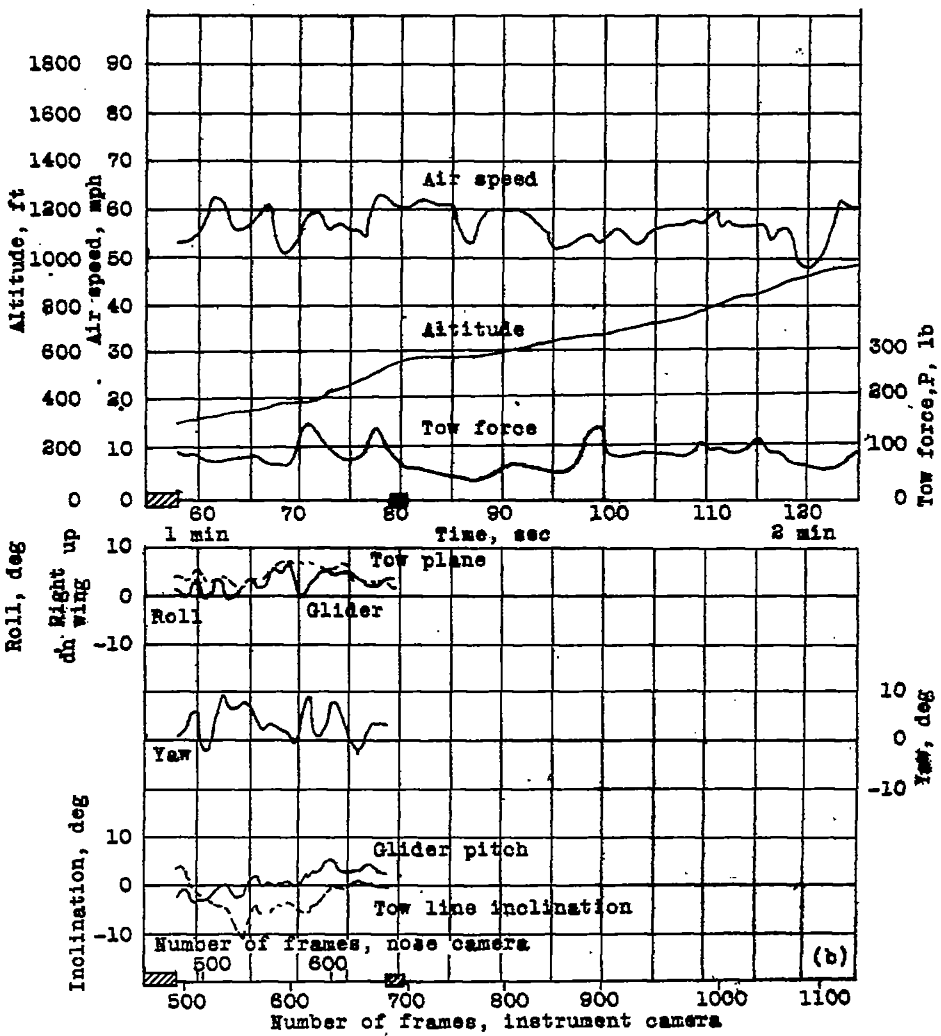

Figure 15.- (Continued)

Flight No. 28

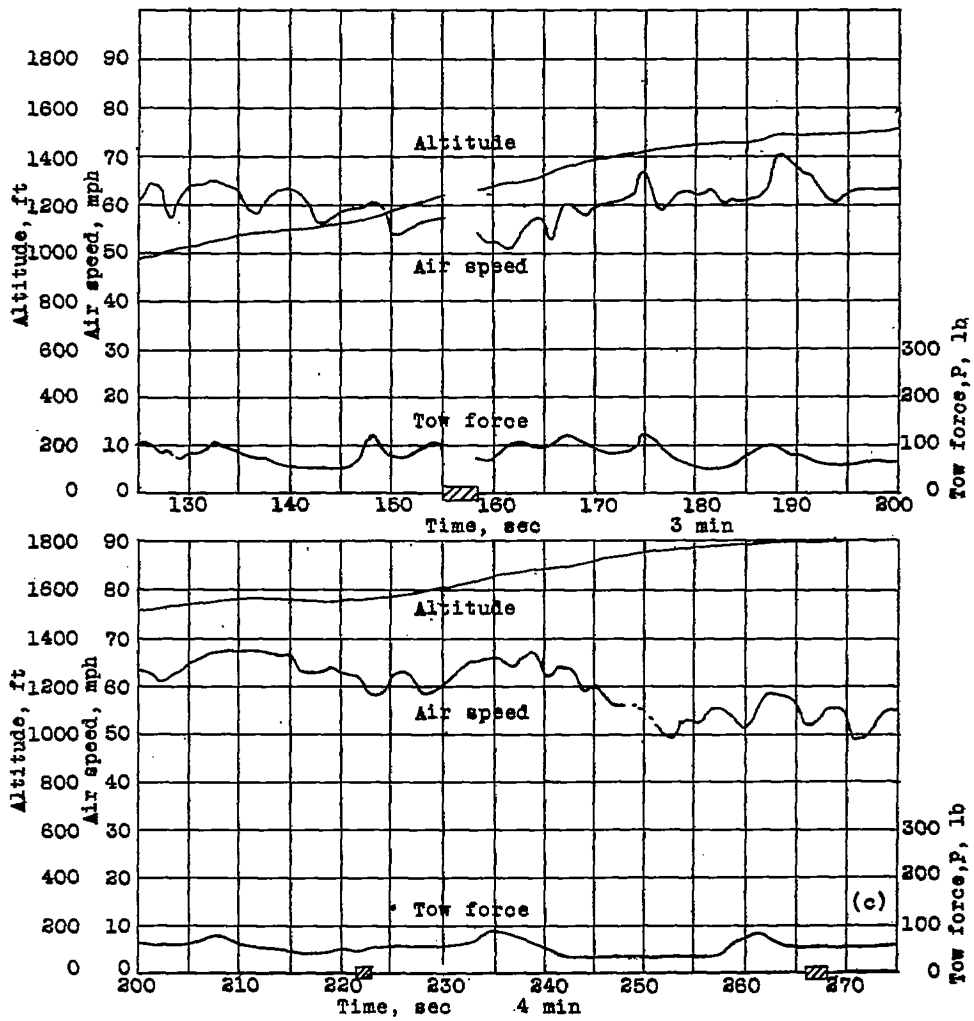

Figure 15.- (Continued)

Flight No. 28

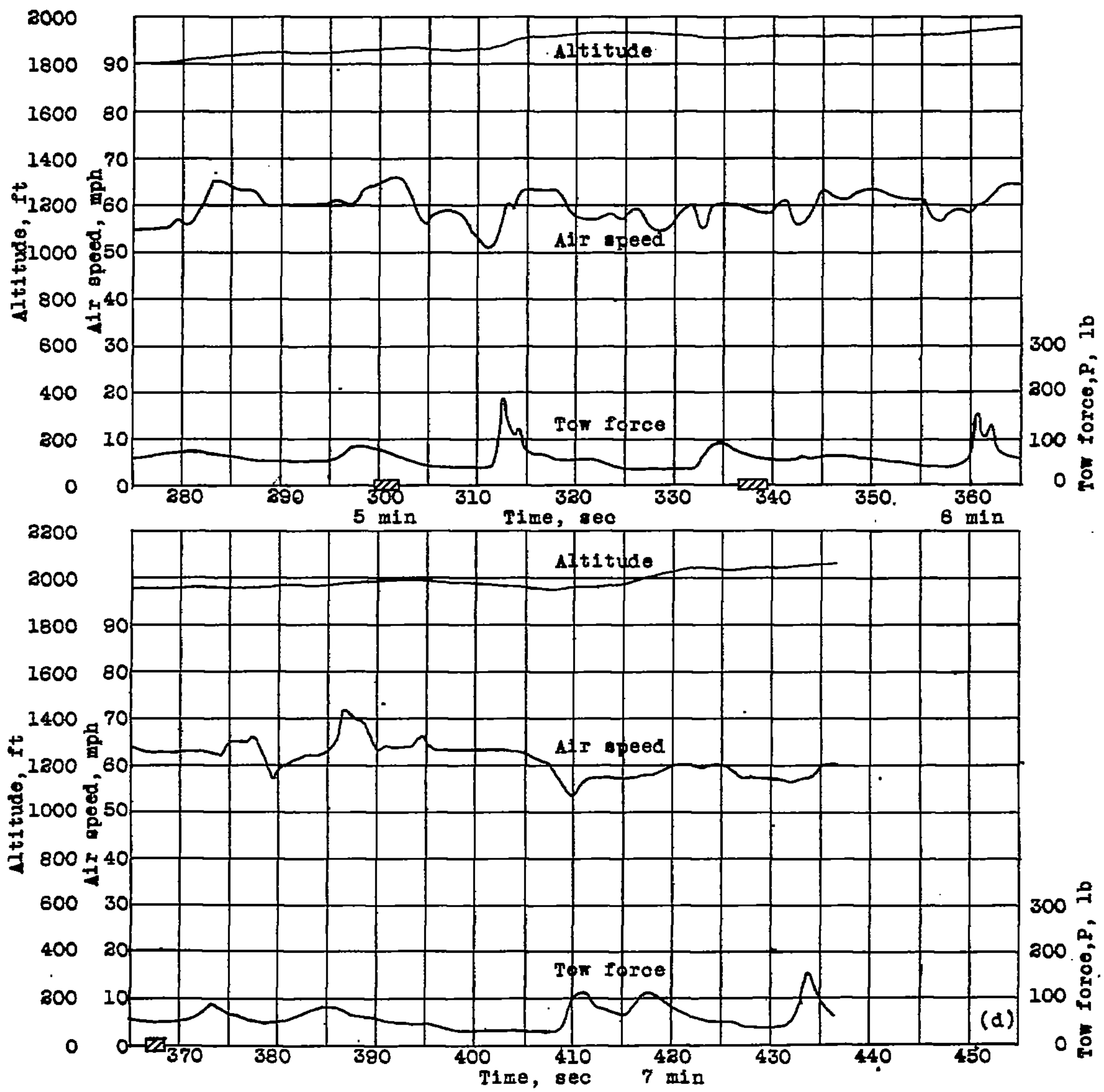

Figure 15.- (Concluded)

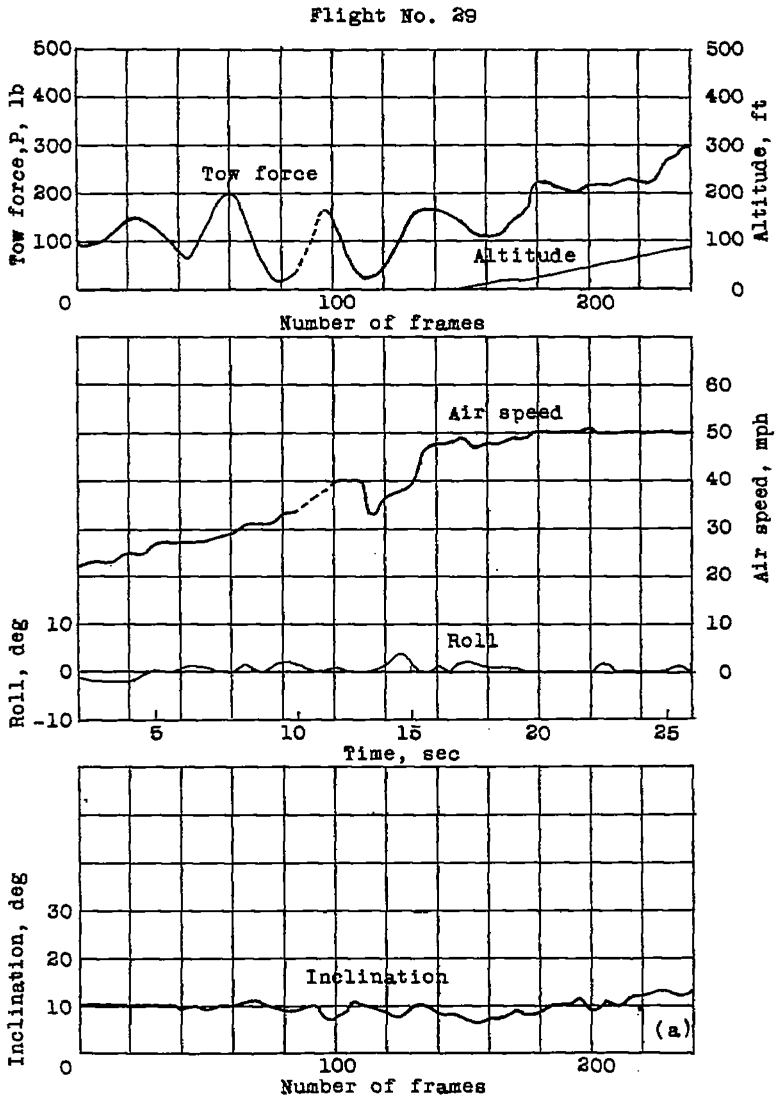

Figure 16(a,b,c).- Results of flight of the Jensen two-seater glider in automobile tow.

Flight No. 29

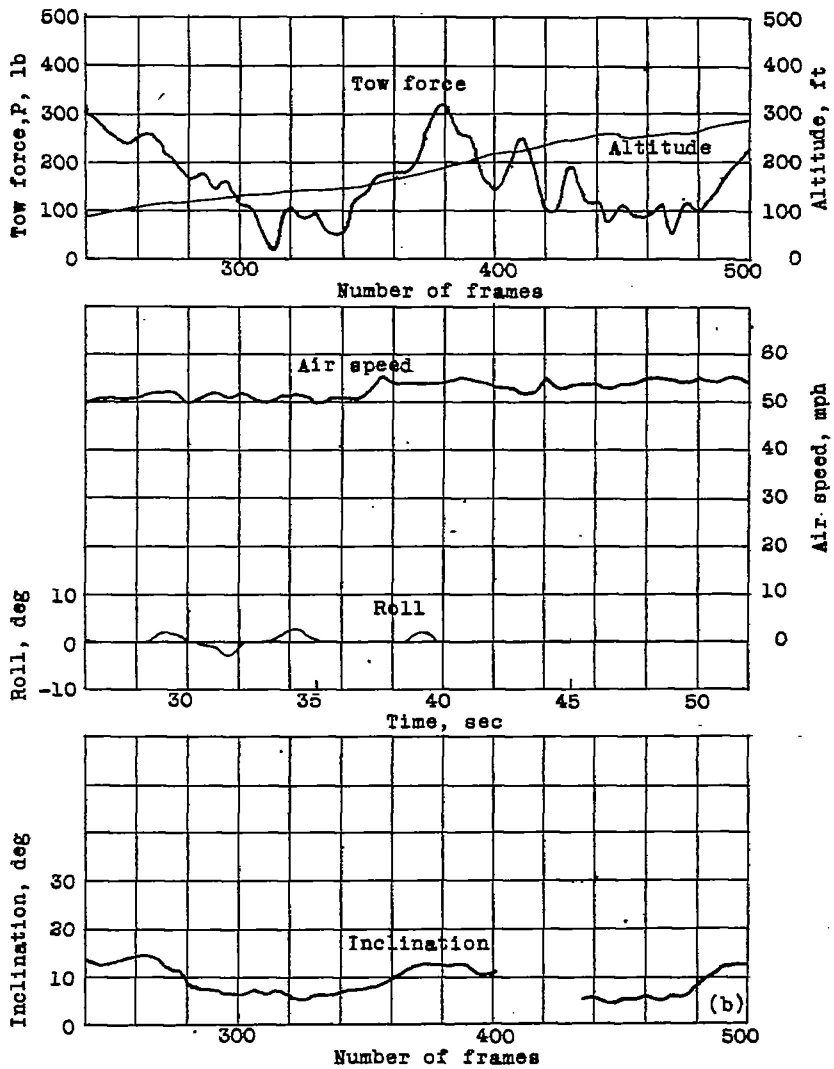

Figure 16.- (Continued)

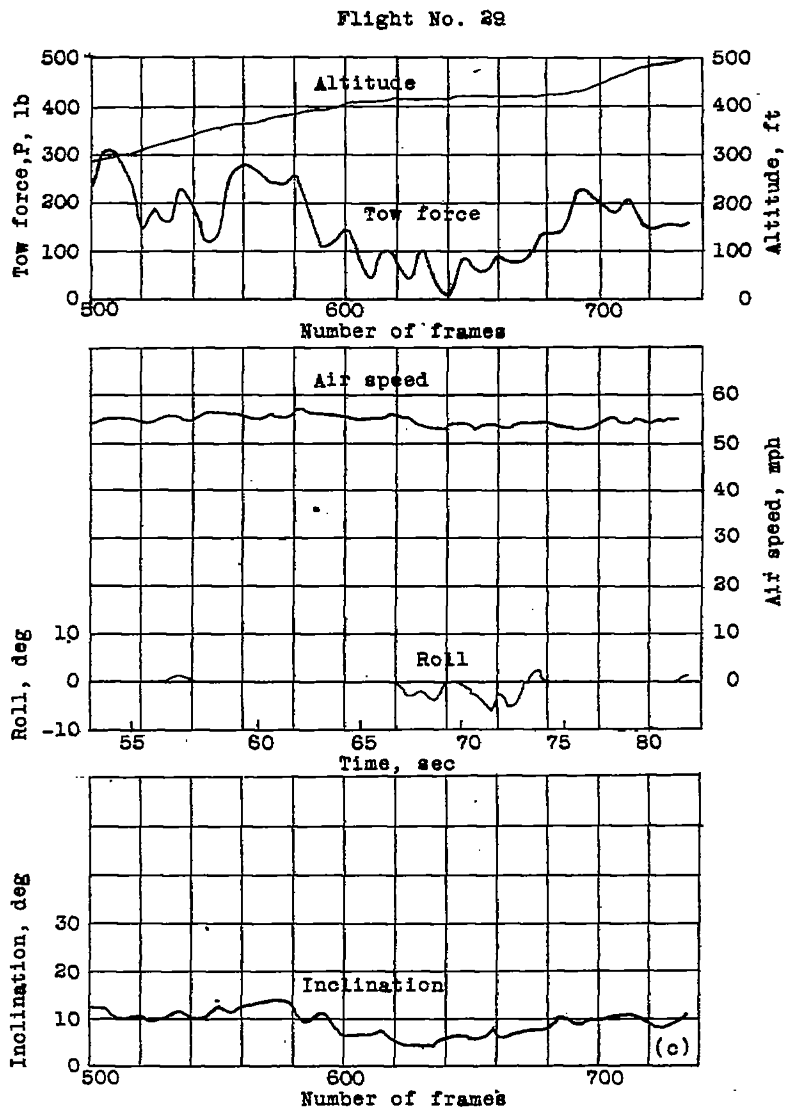

Figure 16.- (Concluded)

Flight No. 34

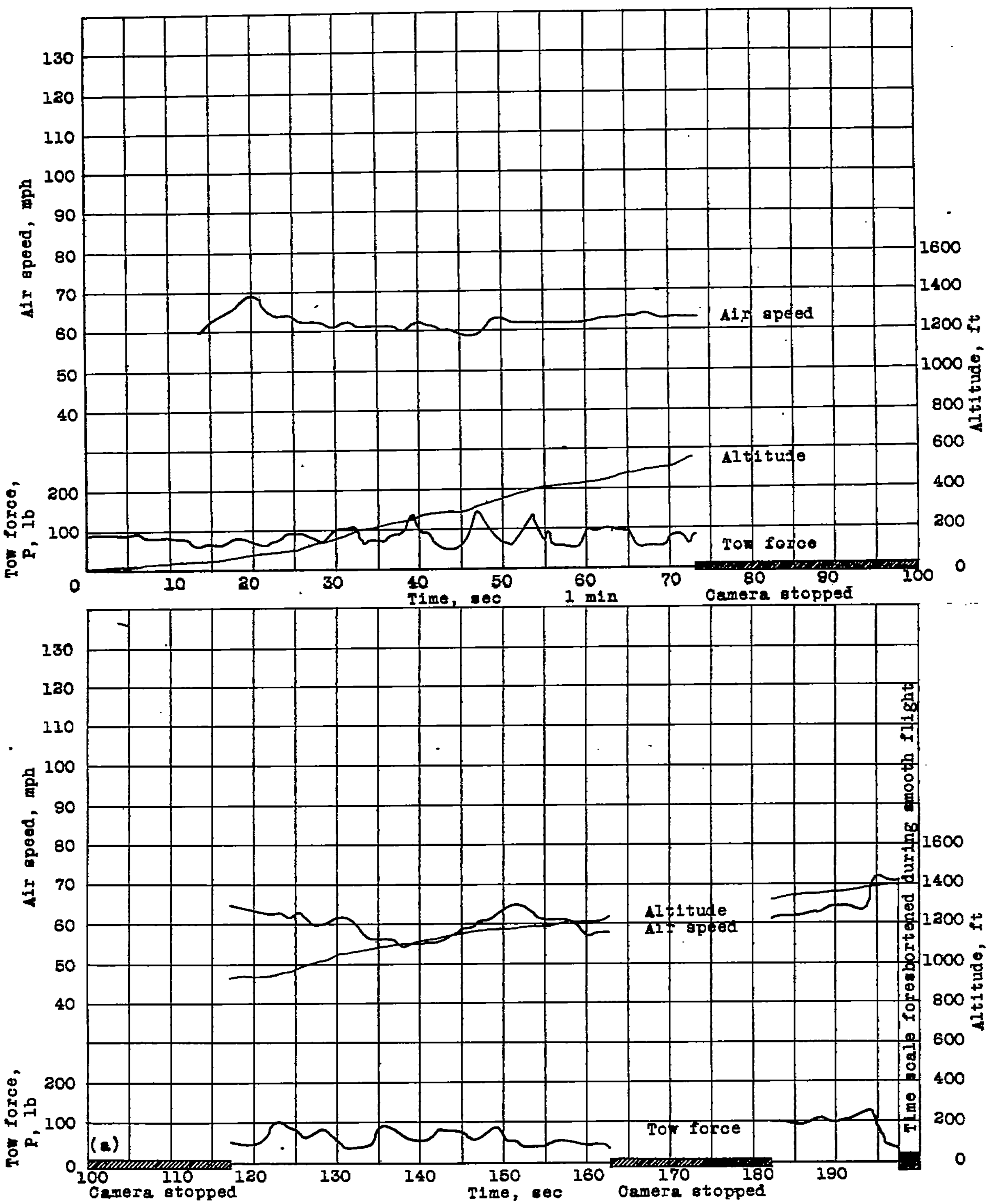

Figure 17(a,b).- Results of flight of Briegleb BG6 glider, yawed violently while in airplane tow.

Flight No. 34

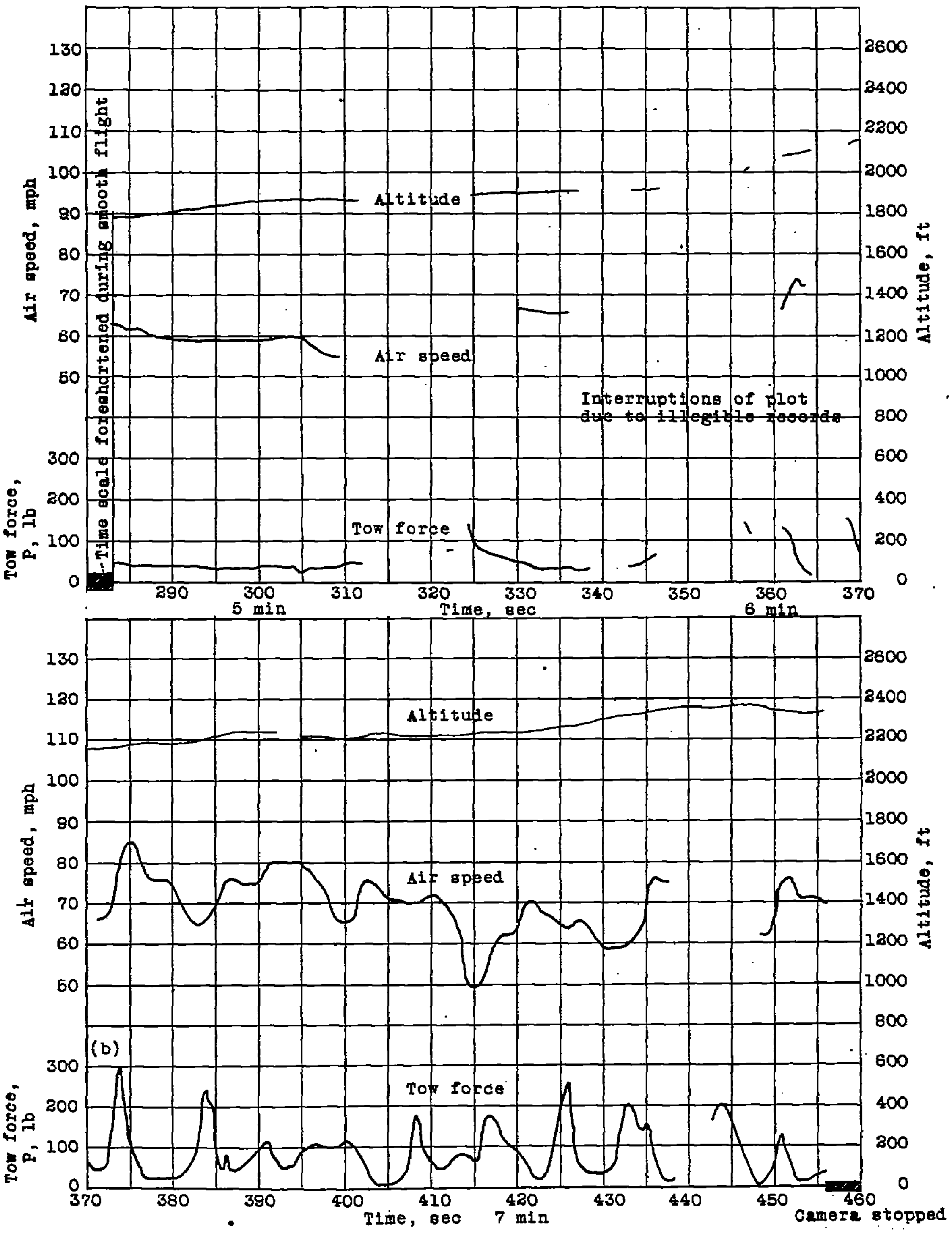

Figure 17.- (Concluded)